STRUCTURE AND FUNCTION

OF

THE KIDNEY.

Smyth. (A.W.)

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INTERPRETATIONS

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OF

THE KIDNEY,

BY

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INTERPRETATIONS

OF THE

Structure and Function of the Kidney.

The anatomy and physiology of the mammal kidney have remained, to this day, as much matters of inference as of observation. There are some points on which our knowledge is complete, but the undoubtedly erroneous theories of the structure and uses of the malpighian bodies have obstructed human thought and progress by false notions of the mechanism of secretion.

To authors and students of surgery the name of Dr. Andrew W. Smyth has for some years been familiar, especially for his great case of ligature of the innominate, carotid and vertebral arteries. His lucid remarks on the collateral circulation in aneurism, published in 1876, proved him to be as earnest a physiologist as he was skilful a surgeon.

For many years past he has persistently objected to the description by Bowman, of the relation between the malpighian bodies and the tubuli uriniferi. With special mechanical aptitude, Dr. Smyth has devoted much attention to the microscope, and he has been subjected even to supercilious criticism for having had one constructed of silver, aluminium-bronze, aluminium, and in part even of gold, that he might possess a perfect, smoothly working instrument in the New Orleans atmosphere which so promptly tarnishes other metals.

Having failed, at all times, to trace a connection between the capsule of the malpighian body and the interior of a uriniferous tube; having likewise observed that the hyaline membrane, enclosing each glomerule, was unprovided with epithelium, essential to every secreting structure, Dr. Smyth perceived that so delicate a sac would rupture, and the plexus be destroyed, if subjected to hydrostatic pressure, either during secretion or from accidental regurgitation.

The only conditions under which the transudation of water, and its collection for onward flow, as universally admitted, could have existed, would have been some mechanism for filtration from the vessels, a contractile reservoir, and a valvular opening into the uriniferous tube. The soundness of this view will appear as we proceed.

The kidneys, lodged in the lumbar region, receive a direct and abundant flow of blood from the aorta, and are more than any other glands under the direct influence of cardiac energy.

They have smoothly rounded contours, and, when their inelastic capsules are pierced, the parenchyma is found granular, compact and solid, normally incapable of expansion and contraction, except as a whole.

At the hilum of the kidney we trace the ureter into the pelvis, into which project the conical ends of the pyramids of Malpighi. From the infundibula, in the conical apices, the straight uriniferous tubes radiate outward; they subdivide, so that their area, with their epithelial contents, increase and expand, into the pyramidal base of the convoluted tubes, towards the outer surface of the kidney. The tubes are individually larger at their orifices than at the pyramidal bases.

The form and structure of each malpighian pyramid indicate a necessary and independent purpose in the mechanism of secretion. For it is evident that a moderate constriction, throughout the substance of the broad base, will cause a rapid and certain flow through the straight tubes and their outlets in the infundibula.

The ample, short and stout, renal arteries, subdivide into straight and important branches, which go directly towards the cortical portion of each pyramid, and here give off terminal branches, right and left, which constitute the afferent vessels of each malpighian body or glomerule.

The artery of each glomerule splits up into coiled loops and branches, which are traced inwards towards the center, and join together to form an efferent vessel. This, on emerging from the hilum of each malpighian body, subdivides into the abundant vascular net-work supplying the convoluted uriniferous tubes.

Having carefully examined the relations of these vessels to surrounding structures, Dr. Smyth perceived that the capsule, wrongly supposed to be the origin of each uriniferous tube, had no intimate structural relation with the ample vessels of the glomerule. It simply sheathed them. It was in fact a periplexus, and by this name Dr. Smyth proposes it shall be known. Around this periplexus are the convoluted tubes, with that abundant spheroidal and polyhedral epithelium supplied by blood from the capillary net work into which the efferent malpighian vessels are divided.

A feature brought out by many injected specimens is the apparently constricted aspect of the efferent vessel. compressed by the more readily injected afferent vessel and its external coils. This is important, according to Dr. Smyth, in explaining how the forces which come into play govern the action of the gland as hereafter to be explained.

In fresh sections of the cortical structure, it frequently happens that a glomerule drops out of its periplexus, and this is seen of extreme tenuity, constituting the boundary of a perfectly empty sac. There is no epithelial lining, and the glomerule when visible fills the cavity entirely or partially, according to its state of distention. This distention is kept within bounds by the manner in which the individual loops sustain each other, and are, *en masse*, when unduly filled, supported by the periplexus.

On the 3d of June, 1879, Dr. Smyth had occasion to extirpate a floating kidney from a woman. For eight years a pain in the right side had rendered life unendura-

ble, and had actually impaired the mind. Dr. Greensville Dowell, of Galveston, Texas, brought her to Dr. Smyth in the preceding month of April, with request that he should attempt the removal of what Dr. Dowell believed, at the time, was the fons et origo mali—the floating kidney. An incision in the right side of the lumbar region, and forcing the organ into its place by pressure upon the abdomen, enabled Dr. Smyth to grasp it. He had anticipated the impression which its strong pulsation produced on his mind, and he asked Dr. C. B. White, one of the attending physicians, to notice this pulsation. Dr. Smyth observed that as the organ filled, under the direct action of the heart, confined as it was in an inextensile capsule, a pressure inward in all directions, from the base to the apex of every malpighian pyramid—from the outer surface of the cortical structure, to the center of the renal pelvis—was inevitable.

This general behavior of the kidney had been his interpretation of the purpose of each malpighian body. This, under the direct pulsating influence of the heart, distends in all directions. The cortical structure is studded in regular and nearly equidistant parallel rows with these spherical objects, capable of equal distention in all directions. Every heart-beat is attended by turgescence of the glomerule. The loops from their position and form must swell outward and inward in all directions, and, constricting the efferent vessel, momentarily impede the blood's exit. At each cardiac diastole, the arterial column sustaining the blood in its channel, the malpighian loops recoil and fill the current in the

secreting vascular rete. And this is Dr. Smyth's view of the special function of the malpighian bodies. Their alternate turgescence constituting a "rhythmic vascular impulse," a uniform, safe and sufficient expelling pressure is maintained on the coiled tubes, and indeed on the whole excreting structure of the kidney.

Those acquainted with the laws which govern the flow of liquids, can readily understand that the power required to maintain a circulation, beyond the coils of the glomerule, would be destroyed, if a mere physical transudation could occur through the loops, so well disposed to bring the very active pulsation to bear on the maintenance of a circulation. A flow outward from the vessel would constitute a leak in the tube. If filtration, as it is termed, had to take place, the blood vessels would have been so disposed, as, when filled, not to press on one another, or against a periplexus—vessel to vessel, and vessels to capsule—in a manner which can only serve to keep the fluid in its regular current. The incompressibility of water is often forgotten, and it is evident, that if at each pulsation a flow had to occur, there would be provision for a relief of pressure and not for its increase at the moment of outlet. That increase inevitably occurs; and if space and structure had been provided for the free and abundant aqueous filtration, is it not evident that the uriniferous tubes, having—for argument's sake—an opening into each periplexus, would be subjected to a strong and intermitting spurt of water, driving before it the epithelium and tending to expose the delicate tube to the destructive action of the urine ?

When the general expansion of the malpighian bodies has driven on the urine, the efferent vessel being then relieved of undue pressure, the blood vessels of the secreting rete, which have also been subjected to systolic pressure, are left free to carry on the blood flow.

The unmistakable constriction of the efferent vessel, on the filling of each glomerule, causes an alternation between clearance of the tubuli and the flow of blood in the secreting vascular rete.

The glomerules are filled during the heart's systole; the secreting rete is turgid during the heart's diastole.

A physiological point to which Dr. Smyth directs attention, is that the commonly received opinion of a portal circulation in the human kidney is not justified by the facts. There is an identity, in so far as a branching of a vein is concerned, if the efferent vessel can be regarded as a vein; but, in truth, no change, or only that due to the slight nutrition of the plexus itself, occurs in the blood as it passes through the glomerule.

It is evident that in a solid glandular organ, confined within a non-extensile covering, a fancied filtration into the secreting tubes, and their consequent distention by systolic pressure, would oppose and obstruct the circulation in the adjacent blood vessels. There cannot be filtration by pressure.* On the contrary, the compression and emptying of the tubuli with the systole of the heart, must proportionally increase the circulation of

*Filtration from the glomerule into the malpighian capsule would, in mechanical effect, be analogous to filtration from the heart into its pericardium. It would arrest the circulation beyond the glomerule—whether the capsule does or does not communicate with the tubuli.

blood through the organ. This is precisely the effect produced by the action of the malpighian bodies. The secreting and vascular structures are not distended simultaneously, but alternately. The expansion of the tubuli, during the heart's diastole, assists the draining into the tubuli from the secreting vascular rete.

We have reason to believe that a low pressure of blood in glandular organs facilitates secretion. The largest secreting glandular organ in the body is situated at the point of lowest blood tension in the circulation. Pressure must antagonize cell accretion, so that relief from pressure during secretion is important.* It can readily be perceived how admirably these conditions are fulfilled in the circulation of the kidney. The distention of the glomerule with constriction of the efferent arteries causes an onward movement to the hilum of the contents of the whole secreting structure. These glomerules are practically reservoirs in a state of fullness ready to supply instantly a large volume of blood at minimum pressure to the secreting rete. The quick, sharp expulsion, and the longer intervals of quiescence, with the incident variations of tension, constitute the best conditions for functional renal activity.

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*In cases of obstructed ureter from impacted calculus, pressure arresting the flow of excreted urine, arrests secretion itself. This pressure in the excreting tubuli, necessarily equal to the force exerted to expel the calculus to the bladder, would, if the tubuli communicated with the malpighian capsules, so distend them as to destroy the structural integrity of the organ. The laws of hydrostatics demonstrate this to be inevitable. The expelling force is the systolic action of the heart, increased by the special action of the malpighian bodies. This is shown by the continuation of the circulation of blood through the organ during the time of this critical pressure, which, in many instances, continues several days.

In accordance with the views herein expressed and in proof of the use and function of the malpighian bodies, a highly satisfactory explanation can be given of the way in which the functional activity of the gland is adjusted to the varying necessities and exigencies of the general system.

When, synchronously with the systole of the heart, the current of blood commences to flow, it goes directly forward through the gland. The condition of the gland at this instant is favorable to such a flow. As soon as the current has acquired a certain degree of velocity, a rhythmical constriction, more or less complete of the efferent artery takes place. The sudden interruption of the onward current by this constriction, forcibly distends the glomerule—increasing the glandular action.* None who are familiar with hydraulics will have any difficulty in understanding the mechanical effect.

*The functional activity of the kidney increases with the circulation of the blood, and with the diminution of pressure during the diastolic period. This result is aided by the hydraulic-ram action of the malpighian bodies, which more forcibly compresses the structures contained within a non-extensile covering. It is impossible to conceive of an increased circulation of blood without a corresponding increase of systolic pressure; so that the functional action varies with the alternations of tension in the gland during systolic and diastolic periods. The systolic tension caused by distending arteries, increased as it is by the consequent sudden interruption of the circulation, and so arranged as to compress and force onwards the blood in capillaries and veins as well as the contents of the secreting tubes, is the most effectual action possible for subsequent diminution of pressure during the diastolic period. The pressure during the diastolic period must diminish with increase of the systolic tension.

We find in organs of quickly varying functional activity, such as the brain and the kidney, constricting arterial plexuses, which, operating in conjunction with the heart's systole, instantly increase, or modify the circulation of the blood; and vary the functional action by varying the tension during systolic, and diastolic periods.

The rhythmical constriction of the efferent artery, following the systole of the heart, it will be seen, governs the action of the gland in the most varied and effectual manner. It regulates the circulation for the double purpose of secretion and expulsion; the obstructed blood is furnished to the secreting rete, at a low tension, and its mechanical energy is utilized in facilitating secretion, and expelling the excrement from the gland.

Thus we have an admirable combination of forces and influences, operating to ensure the adjusted and continued action of the gland. Energy is applied in the most effective manner, to forcibly and quickly expel the secreted fluid. Its retention would arrest the glandular action. Secretion could not go on without expulsion.

So manifest and essential a function is incompatible with the still credited discharge of the greater part, namely, the abundant water of the urine, by the glomerule.

In considering the agencies affecting the blood's circulation, we must recognize the existence of rhythmical variations of tension in many favorably located, free and independent, yet synchronously acting plexiform, vascular loops; and as a result of this, the alternating compression and relaxation of confined organs incapable of expansion beyond the limits of inextensile coverings. That the distention of the arterial system acts as an essential auxiliary in carrying on the circulation of blood is evident.* It rhythmically compresses capillaries, veins

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*It is the pressure from this distention that causes absorption of solidified aneurisms and inactive arterial trunks, after ligation.

and in fact all adjacent structures within their respective enclosures—sacs, sheaths, or similar membranes. And this pressure, regulated by constriction, must necessarily be followed everywhere by correlative relaxation.*

Dr. Smyth many years since directed attention to the fact that the structural circulation of the heart occurred during this organ's diastole.† The cardiac arteries fill when the contractions cease, and the analogy in the circulation of the renal secreting rete beyond the glomerule is obvious. The importance of this in the circulation is evident, when we consider that the heart's diastole occupies more time than the systole, in the proportion, according to Valentin, of three-fifths to two-fifths. It was found by Donders in a large number of observations, that whilst the duration of a complete cardiac revolution varied between 0.640 and 0.806, the duration

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*A continuous, uniform pressure of blood cannot exist in the arterial system; for no organized animal structure is capable of withstanding for any length of time, without remissions, the mean arterial blood pressure. Aneurisms of considerable size, and at some distance from the heart, represent nearly the mean pressure of blood in the arterial system which of course is less than the systolic pressure and we know that all structures, including cartilage and bone, disappear,—are absorbed or destroyed,—even by this tension continuously applied. Neither nutrition nor secretion can go on against such a pressure. We are therefore warranted in believing that all organs having a direct arterial communication, and enclosed within an inextensile fibrous sac, must have their functional action arrested by pressure during the period of the heart's systole. A knowledge of physics enables us to readily understand that an interrupted or intermittent action of the brain may, practically, be of continuous effect. The periods of diastolic laxity are periods of functional action. In fact, it may be said that the sum of these periods constitutes the actual time of animal existence.

†Southern Journal of Medical Sciences, New Orleans, La., February, 1867.

of a ventricular systole fluctuated within very narrow limits, namely, between 0.301 and 0.327.*

The special exercise of energy in the propulsion of blood, by the blood vessels themselves, has long since been regarded as non-existent. The heart is the engine; and the modifying or regulating influences at a distance from the heart, have been defined without reference to any such special action, as Dr. Smyth has so happily discovered. Mr. Bowman was literally correct† when he described the circulation in the malpighian body itself. He said: "A large artery breaks up in a very direct manner, into a number of minute branches, each of which suddenly opens into an assemblage of vessels, of far greater aggregate capacity than itself, and from which there is but one narrow exit. Hence must arise a very abrupt retardation in the velocity of the current of the blood. The vessels, in which this delay occurs, are uncovered by any structure; they lie bare in a cell."

Bowman simply erred in his interpretation of the use of this arrangement; for he thought "it would indeed be difficult to conceive a disposition of parts more calculated to favor the escape of water from the blood than that of the malpighian body." Dr. Smyth has shown, that which is self-evident when perceived, namely, that a simply retarded flow in a tightly packed structure, cannot favor transudation, but does favor expulsion and the blood's vis-a-tergo. The fact that the malpighian bodies of the

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*Hermann's Physiology, translated and edited by Dr. Arthur Gamgee, F. R. S., London, 1878.

†Phil. Transactions, 1842.

parrot and the boa are so minute, and that in these animals the urine is almost solid, was regarded by Bowman as proof of the watery filtration from the glomerule. But on the other hand in these animals the urine is scanty, the uriniferous tubes are small, and the mechanical work of discharge lessened.

In those animals in which the malpighian bodies open into the uriniferous tubes, the expulsive function of the plexuses still comes into play; but nature provides a ciliated epithelium and the structure of the kidney is open and even loose. In the mammalian kidney a ciliated epithelium could not work, and the tubes are filled with an abundant spheroidal secreting lining. No ciliated epithelium crammed in the contorted passages, could effect expulsion like the "pulsating propellers" acting by lateral expansion in all directions, all working in strict harmony, and with admirably distributed force.

The facts that in the evolution of the kidney in the invertebrata, the malpighian capsule is not necessarily a terminal dilation of the uriniferous tubes, and that in some the blind end containing the glomerule, as in bdellostoma, is actually constricted off, lend great support to Dr. Smyth's observations. That the plexus may operate in the renal circulation in the same way, whether the periplexus be perforate or imperforate, is quite clear, and it is also certain that secreting vessels in all glands are disposed in the stroma and secreting membranous walls and not in the form of plexuses of the nature of a glomerule.

Whatever accident may have led to an apparent connection between the delicate sheath enclosing the looped vessels, and the secreting structure with its manifest and indispensable epithelium, it is evident from Dr. Smyth's prolonged investigations, that the condition could not be normal. Messrs. Todd and Bowman thought they proved the continuity in several ways and especially by specimens which had been carefully injected from the artery. In these, not unfrequently, the colored material escapes and extravasates from the vessels of the tuft into the cavity of the capsule and thence into the tube. But such post-mortem infiltration is unverified or not paralleled by the most extensive research in examining normal structures. As Dr. Lionel S. Beale with his usual caution and clearness has said, "In the common newt or eft (triton or lissotriton) we have, so to say, a natural dissection of the elements of the gland structure, and we may *demonstrate* an arrangement, the existence of which we can only *infer*, by an examination of thin sections of the compact kidney of mammalia."

Not only does the presence of the malpighian bodies in animals secreting solid urine refute the idea of a watery filtration by them, but so also do Dr. Smyth's observations on the absence of that essential element in a secreting structure, epithelium, as first shown by Mr. Bowman. Dr. Beale also has said, "The appearance of epithelium upon the surface of the vessel is caused by the loops of capillaries being shrunken and collapsed. When distended with transparent injection, no such

appearance is observable; but here and there a few small granular cells are observed. Masses of germinal matter or nuclei are connected with the walls of these vessels, as well as those in other tissues."

The secretion of urine is constant and incessant. Its expulsion must be equally continuous. Stagnation of this excretion would imply disintegration of tissue; and for this reason, each malpighian body, and the entire kidney, act alike in forcing on whatever has to flow. The velocity of the discharge increases from the time the urine begins to accumulate in the convoluted tube, to its passage to the straight tubes, which, enlarging in individual diameter, actually contract and activate the flow, by a reduction of area in their coalescence. Tardy at first, the ejection into the calices must be rapid and forcible at every heart-beat. Arrest is impossible in so peculiar a gland. The flow is as incessant and involuntary as the cardiac action until muscular passages and a muscular bladder are reached.

The wide bearing of the law now promulgated, that the mechanism of secretion is intimately related to and partly dependent on the direct percussing energy of the heart, is another happy illustration of the complex phenomena resulting from simple mechanical arrangements. Once this aid and stimulus to secretion in the kidney suggested itself, the analogy with the mechanical excitants of the salivary and mammary glands became obvious.

Briefly, the facts tending to disprove the correctness of the theory generally entertained of renal secretion in the mammalian kidney, may be stated as follows:—

1. It is founded on the assumed existence of a permanently open communication between the renal tubes and the capsule of the malpighian bodies. This communication is not stated to have ever been seen by Beale, while its existence has been positively denied by Huschke, Reichert, Gerlach, Bidder, and others. If it existed, there is no reason why it should not as readily be demonstrable, and as often have been seen as the vascular communications.

2. It is based on the belief that water can be separated from the blood by filtration through blood-vessels without the action of glands and without even the presence of glandular structure; and that the filtration takes place against an external pressure at least equal to if not greater than that within the blood-vessel; thus suggesting an exception to the rule of secretion into tubes in the direction of least resistance.

3. It requires the capsule of the malpighian body, an unprotected hyaline membrane, to act as a reservoir connected with tubes excreting a fluid capable of rapidly destroying its structure, as well as that of the glomerule contained within it.

4. In works on the subject the open communication between the tubes and the capsule is shown, in stereotyped diagrams, to be many times larger than the vascular communications of the glomerule.

Every diagram or illustration is on its face a positive demonstration that certain destruction by hydrostatic pressure of both capsule and glomerule must attend an obstructed outlet—a condition known to occasionally occur.

5. The theory is contrary to well-known physical laws as well as to recognized physiological facts.

6. It does not show any mechanism for varying the functional activity in a gland having great variation of functional action.

7. Even if it were demonstrable that there is an actual communication between the tubuli and the capsule, the facts and arguments here adduced would still invalidate the generally accepted theory of renal secretion.

Viewed with clearness and precision the mechanism of renal secretion explains many pathological conditions which have hitherto received very unsatisfactory elucidation.

The pallid, sallow, bloated and enfeebled aspect of a man with heart disease, is but the counterpart of the sufferer from chronic inaction of the kidney. Impairment of the first arrests the functions of the second.

The relation of certain forms of hæmaturia to scanty urine; the resulting anæmia, hectic, and even active blood poisoning, due to a chronic nephritic condition, relieved by astringents, stimulants and generous support, are readily explained.

Dr. Todd long since stated in his clinical lectures, that in contracted kidney, the "coats of the minute arteries, particularly their longitudinal fibres, are often more or less hypertrophied and these vessels themselves frequently very tortuous (the canal of a minute efferent artery being blocked up with oil, while the malpighian body to which it leads is wasted and shrunk up); and the malpighian capillaries are generally thickened and opaque. In some kidneys of this kind, you will find distinct streaks of a whitish material, following the directions of the tubes of the cones; these you may pick out with the point of a knife or a needle, and upon examination you will find them to consist of lithate of soda, which has remained in the tubes. When this deposit is met with in the kidney, the same salt will be found deposited in greater or less quantities in other parts of the body."

No case can better illustrate the evils of a defective clearance of the kidney's structure by impaired mechanism.

Dr. Todd has likewise shown how obstructions to the circulation, due to chronic bronchitis and emphysematous disease of the lungs, with extreme impediment to breathing, may indirectly produce congestion of the kidneys and rupture of the malpighian capillaries. The imperfect aeration and secretion over the respiratory mucous surface, unduly force on the renal secretion. The heart laboring to overcome the thoracic impediments impels with extra force the systemic and hence the renal flow, to

the actual rupture of the terminal arteries of the kidneys, and formation of blood clots.

"Let me caution you," said Dr. Todd, addressing his students, "to keep in view the complications which are apt to accompany these renal diseases." * * * "Of these complications diseased or weakened heart is one of the most frequent, as well as one of the most serious."

A highly instructive and common pathological condition of the kidney, is that attendant on scarlet fever, especially in cold weather. The malpighian bodies are highly congested; their impulse being exaggerated. liquor sanguinis actually flows, not into the periplexus. but into the uriniferous tubes. The urine becomes albuminous and often bloody. The most dangerous and deadly, because permanently most obstructive to urinary secretion, is the so-called glomerulo-nephritis or inflammation directly invading and destructive of the malpighian body.

It is not improbable that these new views relating to the urinary secretion may shed much light on the nature of yellow fever symptoms and complications. A rapidly reduced heart action and typically slow pulse—notwithstanding a continued high temperature,—may explain a mere physical arrest of the kidney's function. Suppression of urine is perhaps the most dreaded of all symptoms; and well may it be, when the restorative influence of a vigorous heart action is impossible with blood changes, extravasations and black vomit.

The presence of tube casts so frequent in the urine is explicable on the theory, that the convoluted tubuli are loops within which the secreted fluid must flow in opposite directions from sites of actual stasis. At these sites tube casts, and, under certain conditions, other urinary deposits are allowed to form.*

Brief and scanty as these pathological references are, they are cited as suggestive of many more. A just interpretation of function is essential to a correct interpretation of disease. It is the faculty for making this interpretation, which I have found conspicuous in Dr. Smyth, that has induced me to commit to writing views which he has developed in repeated conversations. The important parts of this paper he has either written or dictated, and all have received his sanction and careful revision.

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*That the convoluted tubuli are nothing but loops is made clear by the invariable interruptions on attempts being made to inject them, as may be seen in prepared specimens.

New Orleans, La., April 8, 1880.